Expert System for Mine Burial Prediction

Alan Brandt
Johns Hopkins University Applied Physics Laboratory
11100 Johns Hopkins Rd, Laurel, MD 20723-6099
phone: (240) 228-5915 fax: (240) 228-6908 email: alan.brandt@jhuapl.edu

Sarah Rennie
Johns Hopkins University Applied Physics Laboratory
11100 Johns Hopkins Rd, Laurel, MD 20723-6099
phone: (240) 228-8178 fax: (240) 228-6908 email: sarah.rennie@jhuapl.edu

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LONG-TERM GOALS

The degree of mine burial is a crucial factor in Mine Counter Measure (MCM) mission planning, having a significant effect on sensor range and effectiveness. The goal of this project during FY07 was to transition an improved mine burial prediction aid to the Navy Oceanographic Office (NAVOCEANO) to enhance operational Navy MCM decision making. This mine burial prediction tool incorporates recent research in impact burial and seafloor sediment behavior and provides an accurate assessment of the uncertainty inherent in these complex processes and properties in order to allow realistic risk evaluation. Additional burial by time-varying scour processes is being incorporated into the prediction framework.

OBJECTIVES

The objective of the present effort is to enact an expert systems approach to mine burial prediction. The current generation of deterministic, physics-based models provides only a partial representation of the total complex burial processes. In addition, the MCM planner often has limited knowledge of the mine deployment and environmental conditions. Therefore, a probabilistic predictive structure is appropriate. An expert system that synthesizes the current state of knowledge on mine burial behavior has been developed. This model incorporates standard models for mine burial prediction along with improved physics-based models which were developed during the ONR Mine Burial Program (ONR-MBP), as well statistical relationships derived from field observations obtained from both ONR-MBP and NATO projects.

A major goal of this effort, as set forth in the ONR/NAVOCEANO Technology Transition Agreement (TTA), is to transition the MBES into the Environmental Post-Mission Analysis (EPMA) workstation being developed at the NAVOCEANO Warfighting Support Center. Efforts directed towards fulfillment of the transition criteria have focused on documentation of the validation assessment of the MBES predictive performance as well as documentation of the operational shell used by NAVOCEANO to provide input and output connectivity with the expert system. The impact portion of the MBES comprised part of the US contribution to the NATO Naval Group 3 (now Military Capabilities Group 3) Specialist Team for Sea Mine Burial Expert System (ST-SMBES). Further research into the scour portion of the expert system is continuing.

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APPROACH

The Mine Burial Expert System (MBES) has been formulated as a Bayesian probabilistic structure. Models which predict burial by impact or by scour have been developed using the Bayesian software Netica™ (NorSys, 2007) and are implemented as Bayesian belief networks, which represent causal influences among variables as linked conditional probability tables (CPTs). The CPT values are generated from Monte Carlo explorations of physics-based models which have been empirically adjusted to match prior analysis of data sets from the ONR-MBP. (Rennie et al., 2007).

The Netica™ software allows the user to examine different burial scenarios using a graphical interface with which the input distributions that characterize the available knowledge of the state of the mine deployment and environmental conditions can be specified. To provide efficient connectivity with the expert system, a wrapper code for manipulating the MBES network was developed using the Netica™ JAVA-API (Application Program Interface), which embeds the Bayes net functionality within a Matlab program that can manage repetitive I/O requirements, interfacing with sediment databases and producing multiple burial predictions in map form, or capturing statistics of the predictions for validation assessment.

WORK COMPLETED

Transition to NAVO:

As specified in the technology-to-operations Technology Transition Agreement between ONR and NAVOCEANO, work continued on integrating the MBES as a module in NAVOCEANO's Environmental Post-Mission Analysis (EPMA) workstation. Draft documentation of the methodology used to produce the Conditional Probability Tables within the NETICA Bayesian network was provided to the NRL liason to NAVOCEANO. The NAVOCEAN Mine Warfare Program required a science-level model validation assessment to demonstrate readiness which was provided by the completion of the Final Report from the NATO Specialist Team On Mine Burial Expert System (ST-MBES) (NATO MCG/3, 2007).

Improvement in Scour portion of MBES:

The problem of how to interpret a probablistic forecast of a time-varying phenomenon was re-examined. The previous implementation of the MBES scour took as input several independent probability distribution functions of forcing conditions, and a specified duration, which defines the time horizon of the forecast. The forcings are assumed constant over the duration, however, there is an inherent time scale of meterological patterns that must be taken into account to accurately represent realistic conditions. Several approaches to imposing time sequencing on the MBES are being tested, including weighted averaging of input or modifying the Monte-Carlo simulation with an auto-correlation time scale representative of the process as shown in Figure 1 (Avicola et al., 2007). Figure 1 also shows the use of a joint distribution for input wave forcing which will improve MBES predictions by providing more realistic combinations of wave height with wave period.

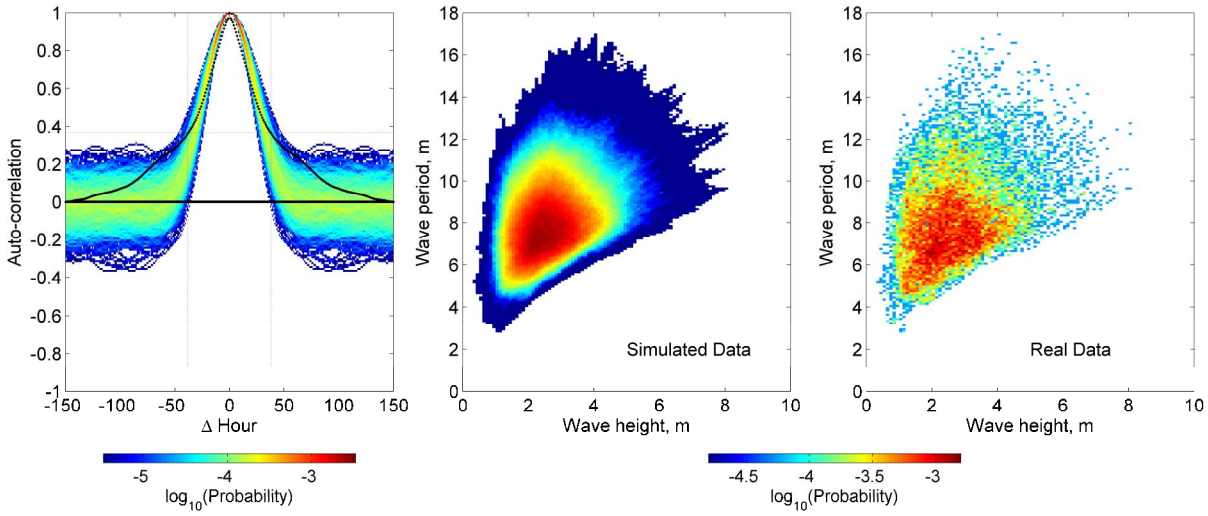

Figure 1. Monte Carlo simulation using auto-correlation sampling technique

RESULTS

Finalized inputs were provided for the Final Report from the NATO Specialist Team On Mine Burial Expert System (NATO MCG/3, 2007). In the Executive summary of,this report it was stated that "Based on the statistical comparison of the experimental data and the SMBES predictions it was concluded that the impact portion of the SMBES has excellent predictive skill and represents a significant improvement over currently available doctrine."

IMPACT/APPLICATIONS

The goal of the MBES is to provide state of the art mine case burial information in a form that can be used by MCM tactical aids to improve the ultimate prediction of the crucial parameter μ, the fraction of undetectable mines in a proposed mine hunting scenario. The expert system acts as a repository for the knowledge generated by ONR-MBP research projects as well as prior (largely ONR) efforts. The Bayesian structure also provides a mathematical formulation for the synthesis of the uncertainty inherent in both input data and model physics. The quantitative error estimation provided by this approach will be an valuable addition to the MCM planning process.

TRANSITIONS

A technology-to-operations Technology Transition Agreement has been signed between the ONR Mine Burial Prediction (MBP) program and NAVOCEANO in which the implementation and testing plan for the MBES is detailed. Resources and staff at NAVOCEANO have been committed to include MBES is as a module in the Environmental Post-Mission Analysis workstation, which will provide desktop risk assessment both at NAVOCEANO and fielded as part of an forward-deployed MCM system where environmental data is collected during the exercise as part of the "Through the Sensors" concept. Discussions with NAVOCEANO as well as N852 emphasized the interest in MBES for increasing the fidelty of burial prediction and for providing the ability to utilize environmental data

now being measured from new sensors. The clear depiction of uncertainty provided by the probilistic expert system was cited as useful both because MCM focus is moving from a clearance-based approach to risk-based, and because the direct relationship to uncertainty in the inputs helps the MCM planner to determine what environmental data missions are most relevant.

RELATED PROJECTS

A review of the engineering scour model used as the core of the scour portion of the MBES was undertaken in preparation for anticipated participation in a Singapore field test. The sensitivities of the model to wave and current combined forcing were reviewed (Avicola et al, 2007). Guidance from the scour portion of the MBES was used in the design the joint Univ. of Hawaii/ NRL Scour field test, funded by ONR, where four of NRL's Acoustic Instrumented Mines are deployed in sand fields near the cabled undersea observatory at Kilo Nalu, Oahu. These data will be used for improving/validating the revised scour portion of the MBES. The MBES is also being used to assist field test planning for Catfish project dealing with the issue of marine IEDs for the Submarine Security Technology program.

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PUBLICATIONS

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